Pion Production in Nuclei Induced by Electroweak Interactions

Shikha Chauhan
Department of Physics, Aligarh Muslim University, Aligarh - 202002, INDIA

Introduction

The neutrino energy region of interest for determining precisely the neutrino oscillation parameters is $E_{\nu(\bar{\nu})} < 3$ GeV. Therefore, most of the neutrino experiments are being done in the energy region of few hundreds of MeV to a few GeV. The neutrino energy region of 1-2 GeV is quite challenging to the theoretical nuclear physicists as the contribution to the cross section comes from the various channels like quasielastic(QE), resonance excitation(RES) and coherent single pion production, multiple pion production, single kaon production, deep inelastic scattering(DIS) processes, etc. For the inelastic process, the neutrino-induced charged current single charged pion production (CC-$1\pi^+$) is dominated by baryonic resonance excitation off a single nucleon bound in a nucleus in the neutrino energy region of a few GeV. The resonance state is followed by its prompt decay into a nucleon and a pion in the final state. Neutrinos can also produce pions by interacting coherently with the nucleons forming the target nucleus, where the nucleus does not change its identity. The requirement to have better neutrino event generator which takes into account the various nuclear effect in each of the reaction channel separately was felt a few years ago and now there are many series of neutrino conferences like NuInt, NuFact, NOW, etc. which are regularly organised to reach a consensus among the theoretical nuclear physicists and experimental particle physicists to better understand the nuclear effect in all the possible channels in the energy region of a few GeV.

In this thesis, we have studied the nuclear effect in the intermediate energy region. This study has been done for the $\nu(\bar{\nu})$ energies of a few GeV and applied to the study of atmospheric neutrinos as well as for the accelerator neutrinos. The study of the nuclear effect has been done for the quasielastic lepton production and the charged current neutrino(antineutrino) one pion production processes. We have studied the lepton event rates for the atmospheric neutrinos at Super-Kamiokande and compared our results with the experimental observed events and also with the Monte Carlo predictions for the events used by Super-Kamiokande collaboration. We have also studied the lepton and pion production cross sections in ν_μ induced reactions in ^{12}C at K2K & MiniBooNE energies and in ^{16}O at T2K energies. The study of π^0 production induced by weak neutral current and magnetic moment interaction of neutrinos and antineutrinos in the energy region of few GeV is also done.

Results

In the case of charged current quasielastic lepton production, the cross section is evaluated as a function of local Fermi momentum and integrated over the whole density of the nucleus by taking into account Pauli blocking, Fermi motion effect, Coulomb effect and RPA correlations in the nuclear medium. We have compared the results of the total scattering cross section with the cross section used in the different Monte Carlo generators. We have also studied the effect on cross section due to the variation in the axial dipole mass M_A, various non-dipole parametrizations for the isovector form factors used recently in the lierature and different versions of Fermi gas models. In the case of incoherent charged current the cross section is evaluated in the local density approximation by taking into account Fermi motion, Pauli blocking, renormalization of Δ properties in the nuclear medium and final state interaction of pions with the residual nucleus. We find that nuclear medium modification on the

Δ properties play a very important role besides the final state interaction of pions with the residual nucleus. Here also we have observe the dependence of the various parametrizations for the N-Δ transition form factors and the variation in the axial dipole mass M_A. We have also studied the Q^2-distribution, lepton momentum distribution and pion momentum distributions.

A. Lepton Events

We have studied the lepton event rates for the atmospheric neutrinos at Super-Kamiokande with and without the nuclear medium effect. We find that in the case of quasielastic process when we calculate the lepton events in the local Fermi gas model without including RPA effect, there is a reduction of around 30% in the event rates as compared to the events calculated for the free case. When we incorporate RPA effect in our local Fermi gas model then there is a further reduction of around 20% in the lepton event rates. In the case of inelastic process the reduction in the event rate is around 25% when we incorporate nuclear medium and final state interaction effect as compared to the events calculated without nuclear medium effect. Therefore, when we calculate lepton event rates with nuclear medium and final state interaction effect in the case of leptons obtained from the inelastic process and the quasielastic lepton production cross section is calculated in the local Fermi gas model with RPA effect along with the quasi-like events, the total event rate reduces by about 40% as compared to the event rates obtained from the inelastic channel without nuclear medium effect and quasielastic lepton events calculated in the local Fermi gas model.

B. Ratio $R(E) = \frac{\sigma^{CC1\pi^+}(E)}{\sigma^{CCQE}(E)}$ of the cross sections.

We have studied the ratio $R(E) = \frac{\sigma^{CC1\pi^+}(E)}{\sigma^{CCQE}(E)}$ of the cross sections for ν_μ induced charged current one pion production process to the charged current quasielastic process for the case of polystyrene(C_8H_8) used in K2K experiment, mineral oil(CH_2) used in MiniBooNE experiment and for the water cerenkov detector going to be used in the proposed T2K experiment. The MiniBooNE experiment has been performed with mineral oil (CH_2) where there are free protons also. Our final result for the ratio is the one where charged current one pion production cross section is calculated for ν_μ induced reaction on free proton as well as from ^{12}C nucleus with nuclear medium and final state interaction effect and the quasielastic lepton production cross section for ν_μ induced reaction in ^{12}C nucleus is calculated in the local Fermi gas model with RPA effect and this also includes the quasi-like events coming from the inelastic channel when a pion doesn't appear in the final state and one only observes a lepton. We find that the ratio R(E) depends on the nuclear medium effect which plays an important role in the inelastic as well as quasielastic processes.

C. Neutral current π^0 production process

We have also studied the π^0 production induced by the weak neutral current and neutrino magnetic moment induced processes and conclude that it is possible in principle to study the neutrino magnetic moment from the observations of neutral current induced π^0 production from nuclear targets in the near detector in future neutrino oscillation experiments by T2K & NOνA collaborations.

The details of the results will be presented in the conference.

References

[1] M. Sajjad Athar, **S. Chauhan** and S. K. Singh, Phys. Rev. **D78**, 037301 (2008).

[2] M. Sajjad Athar, **S. Chauhan**, S. K. Singh and M. J. Vicente Vacas, Int. J. Mod. Phys. **E18**, 1469 (2009).

[3] M. Sajjad Athar, **S. Chauhan** and S. K. Singh, Submitted to Eur. J. of Phys. A, arXiv:nucl-th/0908.1443 (2009).

[4] M. Sajjad Athar, **S. Chauhan** and S. K. Singh, Submitted to J. of Phys. G, arXiv:nucl-th/0908.1442 (2009).